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Band Gap Formation in Fractal-Inspired Mechanical Metamaterials: A Study on the Sierpinski carpet Geometry

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Elastic wave control via mechanical metamaterials has attracted significant research interest, as these structures can exhibit unconventional dynamic properties, including phononic band gaps, arising primarily from their architecture rather than their constituent material.
Among the architectural strategies explored, fractal-based geometries, characterized by self-similarity and scale invariance across multiple length scales, have emerged as promising candidates. Their hierarchical structure offers degrees of freedom for wave tuning that are unavailable in conventional periodic lattices, and has been associated with richer wave propagation behavior.
Despite this promise, the mechanisms by which fractal hierarchy governs band gap formation, and in particular its relationship to the underlying periodic architecture, remain incompletely understood.
To address this gap, the present study investigates the dynamic behavior of a two-dimensional structure inspired by the Sierpinski carpet through systematic finite element analyses in Abaqus. Modal analysis and frequency response analysis under out-of-plane harmonic excitation are performed by varying the fractal generation order n.
The results show that absolute band gaps (ABGs) emerge above a threshold fractal order and closely correspond to those of the equivalent periodic square lattice, defined by the unit cell of the finest scale of the hierarchy. The fractal geometry further modifies the gap structure by introducing localized modes at the internal boundaries between fractal generations, resulting in a characteristic splitting of the primary band gap.
These findings shed light on the interplay between periodic architecture and fractal geometry in shaping elastic wave propagation, and underscore the potential of Sierpinski carpet-inspired designs for metamaterials with controllable dynamic behavior.

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